Available online at www.sciencedirect.com

SCIENCE DIRECT

Renewable and Sustainable Energy Reviews
8 (2004) 493–519

RENEWABLE
& SUSTAINABLE
ENERGY REVIEWS

www.elsevier.com/locate/rser

Current utilization and future prospects of emerging renewable energy applications in Canada

Mazharul Islam *, Amir Fartaj, David S.-K. Ting

Department of Mechanical, Automotive and Materials Engineering, University of Windsor, Windsor, Ont., Canada N9B 3P4

Received 1 December 2003; accepted 19 December 2003

Abstract

Canada has vast renewable energy resources due to its extensive geography and traditionally they have played an important role, particularly prior to the turn of the 20th century. Public interest in new renewable energy technologies (RETs) emerged and grew during the oil shocks of the 1970s and early 1980s. Even though many Canadian provinces had been deriving most of their electricity from hydroelectric power, the first oil crises of the 1970s ignited a strong interest in all forms of renewable energy. Though Canada has huge prospects for low-impact RETs, it is falling behind most industrialized nations in the expansion of these technologies due to a lack of supporting market structures and the absence of appropriate government policies and initiatives. This review focuses on only applications of low-impact emerging RETs that refer to wind, solar, small hydro, geothermal, marine and modern biomass energy. Today, these technologies are mostly in the dissemination, demonstration and early stage of commercialization phase in Canada and currently they contribute less than 1% of the total primary energy consumption. It is evident from the past experience of Europe and Japan that environmentally benign RETs can contribute significantly toward Canada's Kyoto target of reducing greenhouse gas emissions by displacing the use of conventional fossil fuels, and help Canada take an essential step toward a sustainable energy future. In this paper, the current energy utilization scenario of Canada has been analyzed and an array of emerging RET applications has been presented under the category of: (i) green power technologies; (ii) green heat technologies; and (iii) green fuel technologies.

Keywords: Renewable energy; Canada; Solar; Wind; Small hydro; Geothermal; Biomass; Earth energy

* Corresponding author. Tel.: +1-519-253-2000x2631; fax: +1-519-973-7007.
E-mail address: islam1f@uwindsor.ca (M. Islam).

1364-0321/$ - see front matter
doi:10.1016/j.rser.2003.12.006

Contents

1. Introduction . . . 495

2. Present energy scenario of Canada . . . 496

3. Overview of renewable energy sector of Canada . . . 497
   3.1. Institutional framework . . . 497
   3.2. Present utilization of different renewable energy sources . . . 498
      3.2.1. Hydro power . . . 498
      3.2.2. Biomass . . . 499
      3.2.3. Wind energy . . . 500
      3.2.4. Geothermal energy . . . 500
      3.2.5. Tidal power . . . 500
      3.2.6. Solar . . . 501
   3.3. Federal government policy supports . . . 501
   3.4. Provincial and territorial government supports . . . 504
   3.5. Research and development activities . . . 505
   3.6. Barriers . . . 506

4. Emerging RET applications . . . 507
   4.1. Green power technologies . . . 507
      4.1.1. Wind power . . . 507
      4.1.2. Solar photovoltaic . . . 509
      4.1.3. Small hydro power . . . 510
      4.1.4. Biomass . . . 510
   4.2. Green heat technologies . . . 512
      4.2.1. Earth energy systems . . . 512
      4.2.2. Solar thermal water heaters . . . 513
      4.2.3. Solar thermal air heaters . . . 514
      4.2.4. Advanced biomass combustors . . . 514
   4.3. Green fuel technologies . . . 515
      4.3.1. Ethanol . . . 515
      4.3.2. Biodiesel . . . 516

5. Concluding remarks . . . 516

Nomenclature

Abbreviations and acronyms

AWTS	Atlantic Wind Test Site Inc.
BIPV	building integrated photovoltaic
C$	Canadian dollar

CARE	Canadian Association of Renewable Energy
CCAF	Climate Change Action Fund
EES	earth energy systems
ENFOR	energy from the forest
ERES	emerging renewable energy sources
GDP	gross domestic product
GHG	greenhouse gas
GSHP	ground source heat pump
GW h	gigawatt-hour
HAWT	horizontal axis wind turbine
IPP	independent power producer
LFG	landfill gas
MSW	municipal solid waste
MT	megatonnes
MW	megawatt
MW_t	megawatt (thermal)
NRC	National Research Council
NRCan	Natural Resources Canada
PJ	petajoule
PV	photovoltaic
R&D	research and development
RETs	renewable energy technologies
RPS	renewables portfolio standard
SHP	small hydro power
SPV	solar photovoltaic
TW h	terawatt-hour
VAWT	vertical axis wind turbine

1. Introduction

Renewable energy sources have been utilized by mankind since the dawn of civilization through different technologies. Today, renewable energy sources play a significant role in the world and supply more than 14% of the total global energy demand [37]. Over the last three decades (mainly due to oil shocks and environmental concerns regarding greenhouse gas emissions), renewed interest in modern renewable energy technologies (RETs) has opened up opportunities for applying them in diverse fields. Today, the new low-impact RETs industry has demonstrated a global market size of US$ 6.78 billion [28]. This industry is expected to grow to US$ 82 billion by the year 2010 [32].

Canada has vast renewable energy resources due to its extensive geography, and traditionally they have been playing an important role, particularly prior to the turn of the 20th century. For centuries, wood was used for heating and cooking,

while water and wind were initially used for mechanical power and later for electrical power as relevant technologies evolved. Renewable energy provides the majority of Canada's electricity needs, 69,809 MW, equivalent to approximately 64% of Canada's total installed power capacity [13]. In this paper, only the applications of low-impact emerging RETs are considered which refer to wind, solar, small hydro, geothermal, marine and modern biomass energy. Emerging RETs are mostly in the dissemination, demonstration and early stage of commercialization phase in Canada, and currently they contribute less than 1% of the total primary energy consumption [21]. It is argued by the proponents of RETs that if a level playing field is established, emerging RETs will play a significant role in achieving sustainable development while providing reliable and affordable modern energy services in different parts of Canada. In the subsequent sections, the current energy utilization scenario of Canada is presented and then the authors have attempted to suggest major applications of different emerging RETs broadly categorized as: (i) green power technologies; (ii) green heat technologies; and (iii) green fuel technologies.

2. Present energy scenario of Canada

Canada, occupying about 10 million km^2 and having a population of just over 31.3 million, is one of the least densely populated countries in the world. It has strong seasonal changes and large regional variations in temperature. The rigorous climate, the energy intensive nature of the country's industries, and the large distances between population centers result in a relatively high per capita energy use. The energy sector is an important part of Canada's economy in terms of investment, trade, income generation, and employment. Traditionally, Canadian energy policy has been devoted to the development of Canada's large oil, gas and coal resources. Royalty, tax and other fiscal policies, as well as provincial land-use policies, have helped to encourage the development of this non-renewable natural capital. In addition, government support for research and development of new technologies has made the production of bitumen and synthetic crude oil from Alberta's vast supply of oil sands economically viable. The large public subsidy for oil sand development has resulted in it becoming the largest oil resource in Canada, all concentrated in the Fort MacMurray area of northeast Alberta.

Canada was the fifth-largest energy producer in the world in 2001, behind the US, Russia, China, and Saudi Arabia [36]. The energy sector employs more than 280,000 Canadians and accounts for 6.8% of the GDP and 16% of total investment in Canada [18]. In the year 2002, Canada's total commercial primary energy consumption was 288.7 million tonnes of oil equivalent [4]. Canadians use more energy per person than people in any other industrialized nation and on average, each citizen accounts for about 21 tonnes of greenhouse gases per year [22].

3. Overview of renewable energy sector of Canada

In Canada, public interest in new RETs emerged and grew during the oil shocks of the 1970s and early 1980s. Even though many Canadian provinces had been deriving most of their electricity from hydroelectric power, the first oil crises of the 1970s ignited a strong interest in all forms of renewable energy. In the late 1970s, the Government of Canada and most provincial governments responded to the strong public interest in the substitution of oil and other fossil fuels with renewable energy sources. It was recognized at the time, through resource assessment surveys, that Canada had large physical reserves of biomass as well as ample potential of solar, wind, geothermal and other forms of sustainable energy to develop and commercialize. A number of initiatives were started then to research, develop, demonstrate and commercialize RETs. Most Government of Canada expenditures in support of renewable energy occurred in the early 1980s, when it allocated about C$ 100 million per year to expedite the development of technologies and encourage their market penetration [30].

Initial objectives for the market share of emerging renewable energy in Canada were optimistic and successes were not always commensurate with expectations. The lack of quick breakthroughs in technology improvements, as well as the expanding availability of natural gas and low oil prices, moderated expectations for quick market acceptance of new products, especially those based on emerging technologies. On the positive side, renewable energy in Canada has constantly grown in applications where it made economic sense, such as the use of biomass residues in thermal and electrical applications, solar heating of swimming pools, and innovative hydro projects (less than 20 MW). According to the current forecasts of Natural Resources Canada, hydroelectricity will grow to about 398,000 GW h by 2020, while other renewable energy forms, particularly bioenergy and wind, are also expected to grow significantly [30]. The principal driving force will be the need to meet the Kyoto targets of reducing CO_2 emissions by 6% below 1990 levels by 2012. Despite these progresses, the renewable energy share of total primary energy production in Canada will remain relatively constant under the business-as-usual scenario. A brief overview of different aspects of RETs is described in the subsequent sections.

3.1. Institutional framework

The Canadian Constitution divides the power to set energy policy between the provincial and federal governments. The provincial governments own the natural resources, and they are responsible for most aspects of regulation and energy sector development within their geographical boundaries. The federal government is responsible for harmonizing energy policy at the national level, promoting regional economic development, frontier lands, offshore development, and inter-provincial facilities, plus international and inter-provincial trade. Both levels of governments are involved in energy related research activities. At present, there is no special agency for promoting the development of emerging RETs. The sharing of responsi-

bilities between federal and provincial levels of government also requires the introduction of complementary and mutually reinforcing policies at both levels of government. According to the Canadian Association for Renewable Energies (CARE), Canada urgently needs a new agency to promote RETs, which should include federal and provincial departments, utilities, local municipalities and industry, to work collaboratively on exploiting the opportunities offered by renewable energy sources [7].

3.2. Present utilization of different renewable energy sources

Renewable energy power plants have been developed in Canada nearly every year for the last century. The highest levels of additions were in 1971 and 1979, dominated by hydroelectricity projects. About 80% of the total installed renewable energy power capacity is owned and/or operated by integrated electric utilities, while 11% is owned by renewable electricity generator companies, 5% by aluminum companies, 3% by pulp and paper companies, and about 1% by diversified electricity generators who also own fossil fuel power plants [13]. The Contribution of different RETs of Canada is shown in Table 1 for comparison purposes and a category-wise brief overview of major renewable energy sources is given below.

3.2.1. Hydro power

Canada has abundant water resources and a geography that provides many opportunities to produce low-cost hydro power. Canada is the world leader in hydroelectricity production with about 342,000 GW h/year, followed by the US and Brazil [30]. At present, the installed capacity of hydro power plants in Canada is over 67 GW, with a high capacity utilization rate of 50% due to large reservoirs. Hydroelectricity from conventional large- and smaller-scale systems represents 11% of Canada's primary energy supply [20] and is the dominant source of electricity in Canada, representing over 61% of total generation [9]. Most of this hydroelectricity comes from large projects developed by electric utilities and, to a lesser extent, by various industries for their own use. Among all the RETs, large hydro power projects are associated with significant controversies due to social and environmental impacts caused by inundation of large areas.

To avoid the potentially serious impacts associated with large-scale hydro power projects, technologies are also being developed to harness energy from low-head small hydro resources, i.e. falls with a vertical drop of less than 5–6 m. A priority in both areas is to minimize the ecological and environmental effects of energy projects by developing fish-friendly turbines and civil works. Over the last decade, the small-scale hydroelectric industry has contributed about C$ 100 million per year to the Canadian economy in manufacturing and services, and has added about 30–50 MW yearly to Canada's power supply [32]. Canada's small hydroelectric manufacturers and service providers, such as consultants and financiers, also export to overseas customers. BC Hydro, West Kootenay Power, Yukon Energy Corporation, NWT Power Corporation, Manitoba Hydro, Ontario Power Generation, Hydro Québec and Newfoundland Hydro operate or purchase power from many dozens of small hydro plants across Canada [32].

Table 1
Estimates of primary energy production from renewable sources, 1990 and 1999

Source	Electrical energy in GW h		Thermal energy in PJ (input)	
	1990	1999	1990	1999
Hydro	293,980	341,944		
Biomass				
Industrial pulp and paper—electricity from wood wastes and spent pulping liquor	2099[a]	4767[a]		
Independent power production (IPP)—electricity from wood wastes	189	1626		
Electricity from landfill sites	0	670[a]		
Electricity from municipal solid wastes (MSW)	19	19		
Waste water treatment plants	23	58		
Industrial pulp and paper—heat from wood waste			376[b]	513[b]
Residential space heating			84	95
Thermal energy from landfill sites			N/A	2.4
Thermal energy from MSW				12.0
Ethanol from biomass				4.1
Tidal	26	29		
Wind electricity	<1	222[a]		
Solar photovoltaics	<1	6[a]		
Active solar—thermal (water and air)			0.1	1.1
Earth energy systems				1.0
Total renewable energy	296,338	349,341	460.1	628.6

Source: Renewable Energy Market Overview 2000, Statistics Canada and others. N/A; not available.
[a] Current generation is likely higher. Reported generation usually underestimates real activities because of the difficulty in differentiating between various fuels used as input.
[b] Total thermal energy in the fuel used. It includes the electrical output shown under "Industrial pulp and paper".

3.2.2. *Biomass*

Biomass feedstock in Canada include: fuel-wood, wood processing residues (often called "hog-fuel" in western Canada); landfill methane gas; municipal solid wastes (MSWs); industrial wastes; and sewage biogas. There is also an interest in developing additional energy supplies and liquid fuels from crop residues, short rotation energy plantations and agricultural crops such as willow, poplar, and switchgrass. Biomass energy provides a significant fraction (6%) of Canada's primary energy supply, in the form of combustion of wood and wood derivatives for industrial process heat, generation of electricity, and space heating [30]. Biomass from grains such as corn and wheat and from waste streams containing sugar or starch is also used to generate ethanol for transportation purposes. Various emerging technologies based on biochemical and thermal conversion are being adapted to a wide range of biomass applications.

3.2.3. Wind energy

Canada has huge wind energy potential of more than 28,000 MW [20], which represents a significant new environmentally benign sustainable energy source. The country has a long history of utilizing its huge wind energy potential but despite Government support for its development, the country has not embarked on a vigorous wind power program. Today, the total installed capacity of wind power in Canada is 317 MW [11]. During the last years of the 1990s, there was considerable growth in the installed capacity but by end-1999 there was only 125 MW in place. It is reported that by the end of 2000, the capacity had increased to 137 MW, of which 74% was located in Quebec and 25% in Alberta. The current wind industry in Canada consists of about 50 firms, employing approximately 300 people and generating about C$ 18 million in annual sales [30]. At present, some manufacturing of small horizontal axis wind turbine (HAWT) and major components for large-scale HAWT is done in Canada, including towers, fiberglass blades, and all civil and electrical engineering work on site. There are also several small and mid-size vertical axis wind turbine (VAWT) manufacturing companies in Canada [27].

3.2.4. Geothermal energy

It has been demonstrated from research undertaken since 1974 that Canada has plentiful and widespread geothermal potential [42]. Direct utilization of geothermal energy has followed four routes (geothermal heat pumps, aquifer thermal energy storage, energy from mine waters, and hot spring resorts) and provides an estimated total installed capacity of 377.6 MW_t. It has been estimated that 30,000 heat pump units (with a total capacity of 360 MW_t) have been installed in Canada to provide heat and/or cooling to commercial buildings and larger private homes [42]. In some large-scale buildings, the units have combined heat exchangers and aquifer thermal storage technologies whereby recycled geothermal energy is able to provide both heating and cooling. A low-temperature resource at a disused coal mine in Nova Scotia provides an estimated 11 MW_t of direct-use geothermal energy for space heating at a local industrial site. Western Canada is known to possess numerous medium- and high-temperature hot springs and an estimated 6.6 MW_t capacity is utilized for recreational purposes at 11 commercial hot pools and eight resorts in British Columbia and Alberta [42].

3.2.5. Tidal power

The Embayment at the head of the Bay of Fundy between the coastal provinces of New Brunswick and Nova Scotia has some of the largest tidal ranges in the world. The most promising prospects for tidal power have centered on two sites in this region: the Cumberland and Minas Basins. However, the only commissioned tidal power plant is located at Annapolis Royal, further down the Bay of Fundy. This 20 MW tidal power plant came into operation in 1984 and uses the largest Straflo turbine in the world to produce more than 30 million kW h per year [42]. In view of the large tidal energy resource at the two basins, estimated to be 17 TW h per year, different options for energy storage and integration with the river hydro

system have been explored. At present, this prospect appears economically unattractive.

3.2.6. Solar

The solar resource in Canada is generally very good and compares favorably with other regions of the world, due in part to its "clear-sky" climate. The Canadian photovoltaic (PV) industry has grown steadily serving both its domestic off-grid market and the export market. There are approximately 150 organizations actively promoting solar photovoltaic (SPV) power [2]. The Cumulative installed capacity for SPV cells in Canada now exceeds 10 MW [21]. SPV mainly meets the remote power needs of Canadian customers, particularly for transport route signaling, navigational aids, remote homes, telecommunication, and remote sensing and monitoring [2].

An estimated 12,000 residential solar hot-water systems and 300 commercial/industrial solar hot-water systems are currently in use, and energy production from these systems is estimated at around 100 TJ/year [42]. Following the collapse of oil and gas prices in the mid-1980s and the termination of off-oil government programs, sales of new systems have slowed down considerably. Approximately 200 new systems are installed annually, representing sales of less than C$ 1 million [42].

3.3. Federal government policy supports

Under the evolving policy objectives of "energy self-reliance", "security of energy supplies", "energy diversity", "sustainable development", "clean air" and "climate change" initiatives, the Canadian governments introduced many programs over the last few decades in support of renewable energy. These programs took the form of cost-sharing research, development and demonstrations for new energy technologies and, in some cases, fiscal measures that provided tax incentives to encourage the broad market penetration of renewable energy. Other related activities included informing the public about the merits of renewable energy, facilitating the development of standards and training tools, and streamlining regulations. The major federal programs in the RETs sector are described in Table 2.

On December 17, 2002, Canada announced its ratification of the Kyoto Protocol to the United Nations Framework Convention on Climate Change. This protocol obligates Canada to reduce its annual greenhouse gas (GHG) emissions by 240 megatonnes (MT) by the year 2012. The Government of Canada has already adopted a three-step approach for achieving its climate change obligation of reducing annual GHG emissions by 240 MT. First, there are the investments to date that will address one-third of the total reduction (80 MT). Second, it articulates a strategy for a further 100 MT reduction. And finally, it outlines a number of current and potential actions that should enable Canada to address the remaining 60 MT reduction. Provincial and territorial governments are also taking steps to develop comprehensive strategies to help address climate change. They are implementing a range of measures to promote energy efficiency while investing in sources of renewable energy. For example, Canada's cities are encouraging alternative forms of transportation, the use of renewable energy and retrofitting buildings [22].

Table 2
Federal renewable energy policies and measures in Canada [33]

Name of policy	Policy type	Renewable energy	Brief description
Canadian renewable and conservation expenses (CRCE)	Corporate tax incentive	Offshore wind, onshore wind, solar photovoltaic, waste, hydro, solar thermal	The CRCE is a category of fully deductible expenditures associated with the start-up of renewable energy and energy conservation projects for which at least 50% of the capital costs would be described in Class 43.1. The category was introduced in the 1996 budget to allow investors to fully write off certain intangible costs associated with investments in renewable energy and conservation projects.
Climate Change Action Fund (CCAF)	Demonstration project	All RETs	The CCAF was announced by the Government of Canada in 1998 and will invest C$ 150 million in climate change projects over 3 years. These investments are also leveraging significant funding from project proponents and other private sector and government partners.
Ethanol Blended Fuel Reminders	Government Purchases	Biofuel	According to the Alternative Fuels Act, government vehicles are required to use alternative fuels where cost-effective and operationally feasible. To assist fleet managers, Natural Resources Canada's Fleet Wise program provides information and tools aimed at reducing emissions, while at the same time increasing the operational efficiency in the federal fleet and cutting costs.
Fuel excise tax exemption	Sales tax incentive	Biofuel	The incentive amounts to C$ 0.04 for diesel and C$ 0.10 for gasoline equivalent fuels.
Green power	Government Purchases	All RETs	Under this program, the Government of Canada has started using renewable energy to supply their power needs. To qualify, electricity must be generated from new capacity. Green power supplies will have to meet and Maintain EcoLogo certification under Environment Canada's Environmental Choice Program. Electricity will be bought at a premium and emission reduction credits will kept as part of a pilot project to monitor and register such credits.

Table 2 (*continued*)

Name of policy	Policy type	Renewable energy	Brief description
Market incentive program	Grants to renewable energy industry	All RETs	The purpose of this program is to provide incentives to electricity retailers to purchase or produce electricity based on emerging renewable electricity sources from new or expanded generating capacity, or to promote the sales of electricity from emerging renewable energy sources. By offering financial incentives to electricity retailers to purchase or produce electricity from emerging renewable sources (EERES) from new generating capacity, this initiative will increase the competitiveness of EERES to residential and small business customers under green power programs. The objective is to provide a short-term financial incentive up to 25% of the eligible costs of an approved project.
Renewable Energy Deployment Initiative (REDI)	Grants to business users	Biomass and solar thermal	REDI is a six-year, C$ 24 million program designed to promote renewable energy systems for space and water heating and cooling (active solar hot water and air heating systems, high efficiency biomass combustion systems and ground source heat pumps). The program undertakes market development activities in co-operation with renewable energy industry associations and other partners.
Wind Power Production Incentive (WPPI)	Grants	Onshore wind	The Canadian government launched the WPPI, which is expected to boost the country's installed wind capacity by 500% over the next 5 years. The 15-year, C$ 260 million (US$ 170 million) program (the funding for which was announced in the December 2001 budget speech) is designed to support the installation of 1000 MW of new wind power over the next 5 years. The WPPI is expected to leverage about C$ 1.5 billion (US$ 1 billion) of capital investments across the country.

Following a recommendation in 1994 by the Task Force on Economic Instruments and Disincentives to Sound Environmental Practices, Natural Resources Canada (NRCan) studied the feasibility of having the federal government buy some of its electricity from emerging renewable energy sources (ERESs). After consulting with electrical utilities and the renewable energy industry, NRCan announced its intention to start pilot projects to purchase electricity from renewable sources. ERES means wind, solar, water, biomass and the earth power, where the electricity is generated from emerging and innovative applications. NRCan has already started purchasing green power from (a) ENMAX, a utility of Alberta, (b) SaskPower, Saskatchewan's electric utility, and (c) Maritime Electric, Prince Edward Island's utility. Under Action Plan 2000 on Climate Change, it is expected that the federal government will purchase an additional 400,000 MW h or so of electricity from ERESs [14]. Assuming a continued focus on the displacement of high-carbon electricity, these 400,000 MW h will come from several provinces, particularly Nova Scotia, Ontario and New Brunswick, with additional purchases in Alberta. These purchases will result in a further reduction in greenhouse gas emissions of about 200,000 tonnes annually.

3.4. *Provincial and territorial government supports*

In addition to federal government resources, Canada's 10 provincial and two territorial governments also play a key role in the development and commercialization of renewable energy. While federal jurisdiction on the energy market refers to international and inter-provincial trade and facilities, provincial governments are responsible for energy production and distribution within the province. Any regulatory initiatives to increase production must be undertaken at the provincial level. In the case of hydroelectricity, the provincial governments, through their hydro utilities, are the main players in developing and managing these resources. In the past, provincial programs for emerging RETs usually complemented federal government efforts. They were aimed primarily at demonstration projects and/or consumer information initiatives. Although many provincial programs related to emerging RETs have, for the most part, been eliminated, a few provinces maintain some core expertise and programs. Being close to the local scene where projects take place, they continue to provide valuable assistance in terms of project selection, monitoring and dissemination of results.

At the provincial level, a criterion called renewables portfolio standard (RPS), which mandates utilities to generate an amount of electricity from RETs within a time-frame, is expected to be the most important driver for new renewable energy sources in Canada in the future. A mandatory RPS has already been proposed for adoption in Ontario by the end of 2003, under which it will add 3000 MW of renewable capacity to the Ontario electricity system, with roughly half of that to come from wind sources. Beginning in 2004, the Ontario provincial leadership will also begin mandating that all government buildings procure 20% of their power from green energy sources [40]. British Columbia has also adopted a voluntary RPS specifying a minimum of 1.7% new renewables by 2010, this being equal to

about 10% of the additional generating capacity in the province [21]. Several other provinces of Canada are also becoming serious about the procurement of renewable energy sources through the adoption of the RPS. In the near term, several provincial governments are also going to introduce "net metering" which will enable domestic consumers to sell extra electricity generated from the RETs deployed in their houses. This phenomenon will definitely boost the domestic smaller capacity wind turbine and solar photovoltaic market in the urban areas.

3.5. Research and development activities

Programs to assist research and development and commercialization of renewable energy have been in place for over 25 years, funded by various levels of government in response to defined policy objectives [30]. The main funding organizations are the Office of Energy Research and Development for research and development (R&D) and the Renewable and Electrical Energy Division of Natural Resources Canada for market development. The main performer for energy R&D is the CANMET Energy Technology Centre at Natural Resources Canada. In 2000, the federal government of Canada invested US$ 11.99 million on research activities of RETs. This amount is higher than in any of the previous 11 years. Of the total amount, C$ 4.5 million was allocated to biomass, C$ 2.7 million to wind, C$ 1.5 million to small hydro (defined as <10 MW), C$ 1.2 million to SPV, C$ 1.1 million to solar thermal, C$ 580,000 to large hydro, C$ 110,000 to solar thermal electric, and C$ 70,000 each to ocean energy and geothermal resources [7]. Of the total spending in R&D of the energy sector in 2000, renewables received 7.3%, nuclear took 29%, fossil fuels was 24% and conservation received 25% [7].

Canada has always been a world leader in VAWT technology. Research on wind energy systems began in the Low Speed Aerodynamics Laboratory of the National Research Council (NRC) in 1966 [15]. The Atlantic Wind Test Site Inc. (AWTS), a national facility in Canada for the testing and development of wind energy technology, has also been a key participant in the Canadian wind energy program since it was established in 1980. The most promising VAWT related research conducted by AWTS has been dynamically soft Darrieus rotors, a concept which computer models predict will dramatically reduce structural loads [35]. To investigate this, AWTS has initiated a project designed to validate the computer models used to predict the structural responses and aerodynamic modeling and then, with the aid of several consultants, designed a VAWT rotor that could be fabricated at low cost, and could function as a Soft VAWT. The next phase of the project, currently underway, will finalize the design and construct the dynamically soft rotor.

Recently, the Government of Canada has announced C$ 1 billion toward the implementation of the climate change plan for Canada [23]. This investment is part of the Budget 2003 allocation and builds on the C$ 1.7 billion the Government of Canada has invested in climate change over the past 5 years [22]. This investment is an important step toward helping all Canadians reduce greenhouse gas emissions in the short term, but will also open doors to tremendous economic opportunities over the long term through research and technological innovations. Of the total

amount, C$ 250 million will be invested in the development of new technologies that will help reduce emissions over the longer term and seize new economic opportunities. This amount is in addition to the C$ 250 million announced in Budget 2003 toward Sustainable Development Technology Canada and the C$ 50 million towards the Canadian Foundation for Climate and Atmospheric Sciences. RETs are considered one of the major tool for the abatement of greenhouse gases and have a promising chance for getting there share from this climate change related government spending.

3.6. Barriers

There are many barriers hindering the widespread deployment of RETs in Canada. Some of the main barriers are described below.

- The most significant barrier to the RET sector in Canada is lack of pricing for environmental and human health "externalities". The energy marketplace includes several environmental and social externalities, defined as those costs and benefits that do not have a direct financial value but have indirect financial and/or social costs. Externalities include environmental impacts of energy production and consumption such as GHG emissions, toxic wastes, local air pollutants, watershed impacts and human health impacts, among others. There are no well-established market for GHG emissions, clean air or water as of yet and thus no financial cost for their production. Without such price signals, energy projects that have environmental impacts, such as new coal or large hydro power plants, may be subsidized by the public through public funds for environmental clean-up, healthcare or other programs. To add to that, the lack of price signals means that low-impact emerging RETs projects are not rewarded financially for their environmental benefits.
- There is a general lack of familiarity with the technology, and higher transactional costs due to inefficiencies in the marketing infrastructure, as well as a need for the streamlining and harmonization of standards and test procedures.
- RETs often have a higher capital cost than conventional counterparts. This usually discourages potential buyers. However, operating and maintenance costs are greatly reduced and RETs can be quite appealing when considered on a life-cycle basis. The economics of RETs must be compared to alternatives.
- At present, there are no concrete long term policies and goals from the government's side to promote RETs.
- Micro-climatic resource data required for the proper formulation of RETs projects are not easily available in Canada.
- There is a lack of adequate interconnection guidelines, especially for small systems.

4. Emerging RET applications

It is an established fact that emissions of carbon dioxide, methane and other greenhouse gases into the earth's atmosphere are causing anthropogenic climate change, which will bring undesirable consequences for mankind in the future under the business-as-usual scenario. The Canadian government has duly recognized this obvious threat and already ratified the Kyoto Protocol. To meet the Kyoto target, the government has already formulated a Climate Change Action Plan with serious emphasis on greenhouse gas abatement technologies including RETs. Simultaneously, the deregulation of the energy industry and the restructuring of the electricity sector is ushering some forms of competition in the generation and retail markets and providing consumer choice. These two factors are expected to provoke substantial changes in Canadian and global energy markets, favoring the increased use of renewable energy sources.

RETs convert renewable sources of energy to useful energy vectors or carriers, such as heat, electricity, mechanical power or fuels (gaseous or liquid). Applications of different emerging RETs can be divided into three broad categories: (i) green power technologies; (ii) green heat technologies; and (iii) green fuel technologies. In this section, only the technologies that are promising in the near to mid-term from a Canadian perspective will be discussed.

4.1. Green power technologies

Green power can be defined as the electricity generated from RETs from renewable sources like wind, solar, small hydro, geothermal and biomass sources. Today, several jurisdictions in Canada are facing electricity shortages, while at the same time consumers across Canada are facing some of the highest energy costs in the past two decades [12]. In this situation, green power technologies can provide reliable sources of electricity within a short and flexible time frame. In contrast, most fossil fuel plants, large hydro dams, or nuclear plants take several years to develop from the planning to implementation stages. Due to this reason, the development of RETs is a part of Canada's Kyoto obligation along with the goals of energy diversification, technology development, job creation and increased trade. Technology-wise analysis of different green power options are discussed in the following sections.

4.1.1. Wind power

Wind power is the generation of electricity from the kinetic energy of wind. As wind passes through wind turbine blades, it turns a shaft coupled with a generator for the production of electricity. Among the RETs, wind energy has been increasing annually at an average rate of 28% for the last 12 years and currently it is the world's fastest growing source of energy [5]. Over US$ 7 billion was invested in wind energy technologies in 2002 [19]. According to the American Wind Energy Association (AWEA) and the European Wind Energy Association (EWEA), the annual global wind turbine market will be worth over US$ 26 billion by 2010 [1,20]. From past experience, it is evident that wind turbines can compete with

conventional sources in niche markets, and lower costs make them affordable options in increasingly large markets. There are more than 3000 MW of commercially viable wind energy in Ontario alone, which, if developed, would result in more than C$ 4.5 billion in investment and create thousands of jobs in the province [40]. Though the current installed capacity of wind energy is only 317 MW in Canada [11], it is expected that due to increasing awareness in the federal, provincial and municipal governments, the Canadian wind energy market will emerge as an abundant and cost-effective clean energy source for the future.

Currently, there are two categories of modern wind turbines, namely HAWT and VAWT, which are used mainly for electricity generation and water pumping. For the HAWT machines, the axis of rotation of the blades is horizontal, and for the VAWT, the axis of rotation is vertical. The basic advantages of VAWTs over HAWTs are: (1) they are omni-directional, i.e. they adapt to wind from any direction; (2) they are less noisy; and (3) the generator, gearbox, etc. can be placed on the ground. Although there were major research programs and installations of VAWT in the USA and Canada during the 1970s and 1980s, their popularity gradually declined due to more economical fossil fuels resources. Most of the wind turbines installed today are HAWT, largely due to significant investments made by many countries over the last 10 years that have overshadowed progress in VAWT technology. Recently, there has been a resurgence of interest in different types of RETs, including VAWT, because of growing concerns with environmental and energy security [31].

At present, there are about 300 remote communities in Canada that are not connected to the electricity grid [43]. These communities are ideal consumers of RETs like wind. At present, diesel or propane driven gensets are used for supplying electricity and heat in these locations, which is very expensive. In particular, the transport of the fuel to remote areas is costly and labor intensive. Solar photovoltaic installations, on the other hand, are reliable, but they provide very little output in the winter in northern countries like Canada. And this can be reduced to zero if they are covered with snow. In this situation, hybrid power plants of wind and SPV can be opted for, along with a genset for emergencies. Installations of wind turbines with a vertical axis are particularly suitable for areas with such extreme weather conditions. For this purpose, the turbine should not only be quiet and omni-directional, but also should have the lowest possible maintenance expenditures.

Other promising wind power markets in Canada are urban areas. According to statistics, the urban population in North America is about 70% [34]. Every day, about 160,000 people move from rural areas to cities in different corners of the globe. The urban population is growing at a much faster rate than the population as a whole in the world today, and almost half of all people live in urban areas. By the early years of this century, most of the people in the world will live in urban areas [38]. Due to this, increasing amounts of cleaner energy technologies, like RETs, are required for the urban population for sustainable human development. Small straight-bladed VAWTs have a niche market in the urban areas due to their low levels of noise and independence from wind direction [25]. It is expected that if

a cost-effective straight-bladed VAWT is designed, it will make valuable contributions to the renewable component of an urban area's power supply. This new market is potentially enormous. Feeding power directly into the building's own electrical circuits avoids costs otherwise associated with a separate connection to the local utility electrical distribution network [3]. The economic value of the energy is equal to that otherwise charged by the client's electrical supplier, which is considerably higher than would normally be paid for wind energy supplied directly to the grid. Furthermore, wind energy has a stable cost which is not subject to the same volatility as fossil fuel supplies. In fact, the cost of wind energy production is approximately stable for the entire life of the facility, up to 25 years. Many urban consumers in North America and Europe are choosing wind power for this reason, as insurance against spikes in electricity prices caused by volatility in fossil fuel supply.

4.1.2. Solar photovoltaic

Photovoltaic systems use semi-conductor materials to convert sunlight into electricity. Currently, SPV modules generate electricity for homes, cottages, utility grids and traffic signals, and are effective in meeting power needs in remote locations and as an alternative to transmission lines or diesel generators. The future for the large-scale application of photovoltaic power systems lies in two key areas: remote village power applications for the 400 million households worldwide without access to any form of electricity and urban-scale applications as part of new building design, building refurbishment or retrofits to domestic dwellings, commercial buildings and factories. Very large-scale photovoltaic "farms" remain a future application.

Although the SPV market is not large in Canada, its niche market applications and growth potential have attracted several investors. The Bulk of the total installed capacity is used for off-grid applications where PV is proven to be price-competitive against grid-extension or conventional stand-alone power systems [42]. In the SPV sector, the government is actively investing R&D for building integrated PV technology, support for the development of a technical guideline for the interconnection of small power supplies and support for demonstrations of PV on building in high-visibility sites throughout Canada.

In the future, the most promising applications of SPV in Canada will be building integrated photovoltaics (BIPVs), where SPV modules become part of the wall or roof. The electricity generated by the modules is consumed by building occupants, while any surplus power can be sold back to the local utility. BIPV modules can also be manufactured in a semi-transparent format and placed in a window to allow sunlight to pass through. New building products designed for the integration of SPV on sloped roofs, flat roofs, façades and as shading elements have been developed during the 1990s, resulting in the commercialization of more than 50 solar products and support systems specifically designed for building applications. The Integration of SPV into buildings not only offers cost savings, but also improves the aesthetics of the building by integrating the modules into the building façade instead of rack mounting the modules on the roof or on the ground.

At present, commercial and residential buildings account for almost 30% of total secondary energy use in Canada and over 50% of the electricity use [2]. There are almost 7 million detached residential houses in Canada, consuming about 62 TW h of electricity at a cost of C$ 6 billion. If a 30 m^2 PV array were to be installed on the roof of a typical Canadian house, it would supply during the year approximately 4000 kW h or 45% of the electrical load [28]. Also, there are 430,000 commercial/institutional buildings in Canada with approximately 517 million m^2 of floor area. Electricity consumption in this sector is 100 TW h annually (excluding space and water conditioning) or C$ 10 billion in utility bills [29]. The average electricity use in commercial buildings is 193 kW h/m^2 of floor area. If these buildings are fitted with a photovoltaic system, it is possible to supply 65% of the building electricity demand on an annual basis [29]. If the south-facing building façades were also fitted with photovoltaic panels, the photovoltaic system would meet 100% of the electrical load [28].

4.1.3. Small hydro power

Small hydro power (SHP) is one of the most cost-effective RETs, with a high capacity utilization factor. In Canada, the capacities of SHP vary between 20 and 25 MW [26]. SHP systems capture the energy in flowing water and convert it to usable energy. Although the potential for SHP depends on the availability of suitable water flow, where the resource exists, it can provide cheap, clean, reliable electricity. A well-designed SHP power plant can blend with its surroundings and have minimal negative environmental impacts. Moreover, SHP has a huge, as yet untapped potential in most areas of the world and can make a significant contribution to future energy needs. It depends largely on already proven and developed technology, yet there is considerable scope for development and optimization of this technology.

The current capacity of all small hydroelectric facilities in Canada is about 2000 MW [14]. The availability of prospective sites for SHP projects is numerous. Natural Resources Canada has completed an inventory of Canadian small hydroelectric sites. It has identified over 5500 sites with a technically feasible potential of about 11,000 MW. However, only about 15% of that total, approximately 1650 MW, would be economically feasible with current socioeconomic conditions and technologies. If capital costs can be reduced by 10–15%, which should be achievable with future technological improvements, an additional 2000 MW of economically exploitable capacity would be available.

4.1.4. Biomass

Canada has the world's third largest forest area, over 2.4 million km^2, which supports a massive forest-based sector: timber, pulp and paper and a host of associated products [42]. These industries generate very large amounts of residues—chiefly bark, sawdust and shavings from the timber industry and black liquor from the paper industry. Wood-based production of electrical or mechanical energy in Canada uses these residues as fuel. If the availability of surplus residues declines in the future as a result of, for instance, improved mill technologies or increased utilization rates, there is a possibility of wood fiber being grown specifically for use as fuel.

The use of wood waste and spent pulping liquor by the Canadian forest industry amounted to 513 PJ of thermal energy in 1999 [30]. The single largest user of industrial biomass is the pulp and paper industry. In fact, half of the pulp and paper industry's energy needs are met with biomass. The second most important user of bioenergy is the sawmill industry, which often uses wood residues to heat lumber drying kilns. In terms of electrical energy, the pulp and paper industry has about 1500 MW of electricity generating capacity in cogeneration units [30]. Typically, a plant has large boilers that are fueled with biomass wastes and other fuels such as fuel oil and natural gas. The steam produced is used to generate electricity in conventional steam turbines and the balance is then used for processes such as drying. Beyond the pulp and paper industry, several independent power producers (IPPs) were established in the last 20 years which generate electricity from the combustion of wood wastes, usually obtained from sawmills eager to dispose of them. A dozen such plants in Canada with an installed capacity of about 128 MW produce electricity to sell to electric utilities [30].

In recent years, gasification has become an attractive choice for generating electricity from different types of solid biomass fuels like wood, wood processing residues (often called "hog-fuel") and crop residues. Also energy crops, harvested through biomass plantations, are suitable for producing electricity through gasification. The Canadian Forest Service has supported research on energy plantations for many years through the Energy from the Forest (ENFOR) project. The main purpose of this research is to develop fast-growing poplars and willows for the production of forest biomass for energy. During the 1980s, a number of experimental plantation sites were established in Canada for: the selection and testing of hardwood species and clones; the improvement of productivity through hybridization; and genetic transformation and nitrogen fixation for many short rotation tree crops including willows and poplars. Similarly, for agricultural crops, experimental plantations have been established and monitored with switchgrass and other grasses. At present, Canada has over 20 million hectares suited to energy crops [30]. However, the exact potential of energy crop plantation resources is yet to be determined. Although yields from such crops were impressive, there are many technology and economic issues remaining to be addressed.

Landfill gas (LFG) generated at municipal waste landfill sites contains approximately 50% methane (CH_4) and 50% carbon dioxide (CO_2), plus some trace compounds. It is a major source of anthropogenic methane and accounts for 21% of Canada's methane emissions. Methane has a global warming potential 21 times higher than CO_2. There are two ways to manage LFG once it has been captured: it can be flared or used as an energy source. Flaring converts methane into CO_2, a lesser global warming gas. Also, it eliminates odor problems and destroys contaminants. LFG can be used for generating electricity, which can successfully deal with the problem and also conserves non-renewable sources of energy. The Climate Change Municipalities Table Options Report confirmed that it is possible to double the amount of landfill gas captured at Canadian landfill sites, from 6 to 12 MT/year of CO_2 [30]. Such a measure could encourage the generation of

electricity from the captured gas, hence reducing the need for electricity generation from other sources.

Biogas energy is also derived from biomass, which is combusted as a gas comprising primarily methane, the most common constituent of natural gas. Biogas is commonly generated from biomass waste products at sewage treatment plants, solid waste landfills, through forest sector activities, and agricultural operations. Biogas can be produced through a biological process that "digests" the biomass in a chamber with no oxygen, through a chemical process, or through heating in the absence of oxygen. The biomass products are converted to a gaseous fuel. Biogas is then combusted in a boiler to produce steam for power generation through a steam turbine or through a combustion turbine directly. In both instances, under cogeneration applications, the residual heat is used as energy for other applications. In the coming years, these energy sources will play an increasingly significant role for producing green power.

4.2. Green heat technologies

The term green heat refers to four RETs that can be applied to space heating and/or cooling in both residential and commercial buildings, as well as for heating potable or service water. Green heat technologies include: (i) earth energy systems (ground-coupled heat pumps/GeoExchange), (ii) solar thermal water heaters, (iii) solar thermal air heaters and (iv) advanced biomass combustors. Under the Kyoto Protocol, Canada must reduce its GHG emissions by approximately 240 MT by 2012, and greater reliance on green heat technologies in commercial and residential space and water conditioning applications could reduce these emissions by up to 84 MT. The Renewable Energy Deployment Initiative of Natural Resources Canada was established in 1997 to stimulate the demand for RETs for space and water heating and cooling, and it has identified the above-mentioned RETs as green heat technologies.

In 2001, the GreenHeat partnership was launched by the CARE [24]. This partnership involves a number of members from the Earth Energy Society of Canada, the Canadian Solar Industries Association and the Canadian Biomass Association, as well as a growing number of private companies. The main focus of the partnership is to promote the economic and environmental benefits of Green Heat technologies in the context of Canada's ratification of the Kyoto Protocol, and to ensure that Green Heat is recognized as a viable option in any national implementation process. The GreenHeat partnership involves suppliers from the four renewable energy space conditioning technologies, who want to help Canada meet her reduction targets for GHG emissions. This initiative will increase understanding of the significant role that renewable energies can provide in space heating, space cooling and water heating and thereby facilitate the transition to greater use of renewable energies in Canada.

4.2.1. Earth energy systems

The geothermal heat pump or ground source heat pump (GSHP) system has come to be known as the "earth energy system (EES)" in Canada, using subsurface

solar-heated earth or water as a main heat source and sink in order to provide heating or cooling [17]. Natural heat from the earth or water source is absorbed into a liquid heat transfer medium circulating in buried pipes and carried to the building. It is then upgraded to a comfortable room temperature through a heat pump unit. When cooling is required, the system is reversed. Heat is returned to the cooler ground and/or water source and is again transferred back to the building, where it is distributed at cooler temperatures. Ground source heat pumps use the earth or ground water as a source of heat in winter and as a "sink" for heat removed from indoor air in summer.

EESs are primary energy production devices. While they require electrical energy to power their loop and heat pumps, EESs typically generate three to four units of energy output per unit of input. There are approximately 30,000 residential EESs in Canada [30]. Annual sales peaked in the early 1990s, primarily as a result of an Ontario Hydro incentive program. During that period, Ontario Hydro provided cash incentives for the residential installation of GSHP in areas not serviced by natural gas.

4.2.2. Solar thermal water heaters

Solar thermal water heating systems use collectors that convert sunlight into heat in order to warm water for domestic use, such as radiant floor heating systems, outdoor or indoor swimming pools, or industrial and commercial facilities such as car washes or laundries. Systems can be designed to provide seasonable or year-round heating, with a choice of collectors that can heat water to any temperature, including boiling. Storage tanks are usually used to maximize the collection of solar energy, and to ensure that the system can provide hot water on demand. At present, approximately one-fifth of the total energy bill in an average Canadian home is spent on the heating of water, which makes solar thermal heat a very cost-effective application of the technology [10].

Residential water heating is a solar heating application that has recently received renewed interest in Canada from the private investment community, utilities and energy service providers. Water heating in Canada currently accounts for approximately 20% of the residential energy use, representing about 15 MT of CO_2 emissions per year for an average of 2 tonnes of CO_2 per water heater [30]. Solar water heaters can make a significant contribution to CO_2 emission reduction as each installation reduces conventional energy use by 40–50%. There are approximately 12,000 solar water heaters currently in use in Canada, representing less than 1% of the market [30]. Market penetration has been limited to date primarily due to high cost. New, advanced, low flow solar water heaters have been planned for commercialization that should have a significant impact on the market. Through assistance from the Climate Change Action Fund (CCAF), utility partners should install about 100,000 units over the next 10–15 years, delivering energy at a cost to the consumer of approximately C$ 0.05 per kW h, competitive with electricity and natural gas prices.

Pool heating is another promising application where solar technology should increase the market share. More than 600,000 Canadian homes—about 10% of the

total low-rise housing stock—have outdoor swimming pools and approximately one-third of these are heated. Solar heaters currently have about 10% of the market share, representing more than 20,000 units [30]. The main barrier to increased market share has been lack of awareness of the cost/benefits of solar heating. Recent studies in Canada concluded that solar pool heaters could provide the performance that pool owners desire and have a simple payback ranging from 2 to 4 years. The studies indicate that solar heating could capture 40–50% of the pool heating market in the long term. Test promotions during 2001 at three locations in Canada confirmed this potential.

Other water heating applications in Canada where solar technology is expected to gain market share include aquaculture process water heating (fish hatcheries) and car washes. There are approximately 1500 car wash facilities across Canada, consuming a total of 17 million m^3 of hot water per year (>2 PJ/year) [30]. There is a trend toward more touch-free facilities which use double the hot water compared with the more conventional friction type washes due to the use of warm water for both the wash and rinse cycles. Studies show that the solar heating for such car washes can result in payback periods ranging from 5 to 7 years.

4.2.3. Solar thermal air heaters

Solar air heating typically consists of perforated vertical collectors that are installed on the south-facing exterior of larger facilities such as factories and warehouses. As the air is sucked into the collectors and rises, it is heated by sunlight to reduce the heat requirements inside the building. This technology has been installed on a large number of sites in Canada. The acceptance of this technology is strongest in commercial and institutional applications, but residential buildings can also benefit from lower heating costs and the improved ventilation that is offered by solar-heated air. The leading solar air heating product in Canada is the "SOLARWALL" technology. This dark-colored cladding is attached to the side of a building, serving the dual role of protecting the wall and heating and/or cooling the building. Fresh air enters the base of the south-facing SOLARWALL and is collected at the top to be ducted to a rooftop fan that circulates it throughout the building [16].

4.2.4. Advanced biomass combustors

Because of the extensive land base available in Canada, there is large physical potential for additional solid, gaseous and liquid fuels and chemicals, as well as electrical energy from biomass in Canada. Using wood for residential space heating and cooking has a long history in Canada and around the world. While most Canadians now prefer the convenience of electricity and fuels like natural gas and fuel oil, wood heating remains part of the Canadian way of life. About one-third of all Canadian households have wood burning equipment. The incidence of residential homes using fuel-wood is highest in Atlantic Canada (especially Newfoundland and Labrador) and lowest in the Prairies. Survey results show that there are over 1.5 million Canadians who use wood for home heating, while another 1.5 million households use wood as a secondary source of heating [30]. In addition to

home heating, wood is used for commercial and institutional buildings. There are numerous other biomass space heating applications, including district heating systems, farm use, rural stores, schools, hospitals, and government buildings. Most of these are small capacity systems in the 50–300 kW range.

Technology advances over the past decade are making residential wood heating a more attractive proposition. Advanced biomass combustors with catalytic combustion technologies minimize the amount of smoke and other air pollutants. Particulate emissions are reduced by about 80% relative to conventional stoves manufactured before the mid-1980s. The systems allow for a more complete combustion of the fuel and consequently provide more heat inside the house than conventional stoves. Also, the aesthetic appeal of the new stoves is greater, as large ceramic glass windows allow the homeowner to view the flame without sacrificing efficiency.

4.3. Green fuel technologies

Green fuels (also called biofuels) are basically derived from various biomass sources. Green fuels are highly desirable because they can easily be used as a sustainable transport fuel. At present, ethanol and bio-diesel have been marketed as green fuels in Canada.

4.3.1. Ethanol

Ethanol is sold in Canada as a high-octane fuel that helps reduce air pollution while delivering improved vehicle performance. In Canada, six plants with a total capacity of 244 million liter per year produce ethanol via this process [8]. This conventional ethanol costs 20–30 US cents per liter, and in the US an incentive of 14 cents per liter is paid by the federal government to assist blenders [21]. The Canadian ethanol industry is relatively new and growing. Ethanol was first blended and sold in Manitoba 20 years ago. Gasoline is now available with 5–10% blended ethanol at approximately 1000 locations in six provinces (the four western provinces, Ontario and Quebec) [30]. The support of the federal and provincial governments has been crucial to the development of the ethanol industry. Tax incentives, research, procurement policies and political will are providing a kick-start to the efforts of farmers, manufacturers and environmentalists to make ethanol an excellent alternative to conventional fuel sources for Canadians.

Ethanol can be produced by the fermentation of sugars and starches from various crops and particularly from corn or wheat. It is also possible to produce ethanol by the breakdown of cellulose to its component sugars using enzymes, and in Canada, Iogen Corporation has developed this process and has constructed a pilot plant in the Ottawa area to demonstrate its feasibility. This process can use agricultural waste, and currently the economics, in the Ottawa area for example, are best with wheat straw. Iogen has entered into a partnership with Petro Canada and with Shell to further develop this bioethanol and bring it to market. Its pilot facility now processes 50 tonnes of wheat straw per week into fermentable sugars. Its goal is to produce 700,000 l of ethanol per year in an ethanol plant planned for construction in 2004 [21].

Studies have shown that greenhouse gas reductions are possible with ethanol produced from biomass, as compared to non-renewable fuels, on a full life-cycle cost basis. Based on Argonne National Laboratory analyses, ethanol in the form of E85 (85% ethanol blended with 15% gasoline) derived from cellulosic biomass can reduce carbon emissions in the range of 80–85%. In contrast, corn derived ethanol, in the form of E85, achieves an about 22% reduction in carbon emissions [6].

4.3.2. Biodiesel

Biodiesel is a cleaner-burning diesel replacement fuel made from natural, renewable sources such as new and used vegetable oils and animal fats. It can be used in concentrations up to 100% in many engines built since 1994 with little on no modification. The American Biofuels Association claims that biodiesel sales could reach about 2 billion gallons per year or about 8% of highway diesel consumption with incentives comparable to those given for ethanol [21]. The current cost of biodiesel is between US$ 1 and 2 per US gallon with production from fats and grease at the lower end. Biodiesel was tested successfully for cold climate operation in the Montreal bus fleet in 2002–2003. The Société de transport Montréal would like to deploy biodiesel in its bus fleet and Rothsay-Lorenco are prepared to build a plant to supply the biodiesel provided the provincial government eliminates its fuel tax. They are now waiting for a response from the provincial authorities.

5. Concluding remarks

The aim of this paper was to analyze the current energy utilization scenario of Canada and thereby suggest prospective emerging RETs from a Canadian perspective. The prospective applications of different emerging RETs were broadly categorized as (i) green power technologies; (ii) green heat technologies; and (iii) green fuel technologies. It has been demonstrated in the preceding sections that these environmentally benign technologies can contribute significantly toward Canada's target of reducing greenhouse gas emissions by displacing the use of conventional fossil fuels, and can help Canada take an essential step toward a sustainable energy future. In addition to climate change abatement measures, wide implementation of renewable energy will also provide benefits to the economy in the long term [30]. It is often mentioned that many of the new technologies and products will provide local employment and other social benefits. Strong expertise in certain areas can help exports of goods and services.

Renewable energy has lately received a lot of attention all over the world, in particular from the media, government policy makers, energy industry, and environmental and other interest groups. However, despite expectations and many efforts by governments to promote and subsidize the use of renewable energy resources, renewables still face high entry barriers in energy markets in Canada. Bold leadership and political will are a must for a successful RET program, which has been demonstrated in European countries. Increased government spending is

crucial for fostering the development of the RET sector through increased research, development and demonstration.

Though the renewable energy market in developed countries like Canada is considered to be driven by environmental issues, in the very near future the North American market could also begin to feel energy-driven growth as electricity markets transform under a deregulated structure. In the future, capacity growth will severely strain many existing transmission and distribution systems in North America and Europe. Under deregulation, utilities are being separated into generation, transmission and distribution components and new entrants have become significant participants in the generation of electricity as the industry moves toward deregulation. The construction of new power-generating plants and transmission lines to meet new demand has virtually halted as companies wait to understand the effects of deregulation of the electric utility industry. This imbalance becomes even more threatening amid projections that electricity demand will grow 17% by 2007 as transmission capacity rises only 4% [32]. The Recent "blackout" in Canada and the USA on August 14, 2003, has already shown the vulnerability of the North American grid. It was the largest power outage in North American history, affecting an estimated 10 million people in Southern Ontario, Canada (about one-third of the population of Canada), and 40 million people in eight US states (about one-seventh of the population of the US) [39]. If both governments allocate 10% of funds to upgrade the grid earmarked to RETs, as suggested by the Canadian and US solar industry associations, RETs will be able to maintain a "smart grid" that includes time-of-day pricing and financial incentives to deploy RETs that provide back-up and emergency power.

RETs promotes sustainable development, which means meeting the needs of the present without compromising the ability of future generations to meet their needs [41]. The main culprits obstructing sustainable development are conventional fossil fuel and nuclear energy technologies, which are accompanied by environmental degradation at local, regional, and global levels that threatens human well-being now and well into the future. This degradation threatens human health and quality of life in the short-term, and affects ecological balance and biological diversity in the long term. But, RETs harnessed from the natural ecosystem (like solar, wind, hydro and biomass energy sources) are environmentally benign and inexhaustible. Due to increasing efforts by the global community to combat greenhouse gas emissions from conventional fossil fuel technologies, RETs will play a significant role in the coming years.

Acknowledgements

This work was financially supported by the Natural Sciences and Engineering Research Council of Canada (NSERC).

References

[1] American Wind Energy Association (AWEA). Global Wind Energy Market Report, 2003. Available from: http://www.awea.org.
[2] Bailey LD. Photovoltaic technology status and prospects: Canadian annual report 2002. CANMET Energy Technology Centre, Varennes, Natural Resources Canada, Canada; 2003.
[3] Blanch MJ. Wind energy technologies for use in the built environment. Wind Engineering 2002;26(3):125–43.
[4] British Petroleum. Statistical review of world energy 2003, UK; 2003.
[5] BTM Consultant ApS. International wind energy development, world market update 2002, forecast 2003–2007, March 20, 2003.
[6] California Energy Commission. Evaluation of biomass to ethanol, fuel potential in California. California, USA; 1999.
[7] Canadian Association for Renewable Energies (CARE) 2003, web site, http://www.renewables.ca.
[8] Canadian Renewable Fuels Association 2003, web site, http://www.greenfuels.org.
[9] Canadian Electricity Association 2003, web site, http://www.canelect.ca.
[10] Canadian Solar Industries Association (CanSIA). Solar energy in Canada: a brighter look into the future, Ontario, Canada; 2003. Available from: http://www.cansia.ca.
[11] Canadian Wind Energy Association (CanWEA) 2003, web site, http://www.canwea.ca.
[12] Canadian Wind Energy Association (CanWEA). Wind vision for Canada—10,000 MW by 2010 (10×10), Canada; 2001.
[13] Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC). A review of existing renewable energy facilities in Canada. Canada, March, 2003.
[14] CANRen of Natural Resources Canada web site, http://www.canren.gc.ca.
[15] Chappell MS. Wind energy research and development at the National Research Council of Canada, NRCC No. 27459, October 1986, Canada.
[16] Conserval Engineering Inc. 2003, web site, http://www.solarwall.com/sw/solarwall.html.
[17] Earth Energy Society of Canada 2003, web site, http://www.earthenergy.ca/conta.html.
[18] Energy Council of Canada 2003, web site, http://www.energy.ca.
[19] Energy Info Centre of World Energy Council. 2003, http://www.worldenergy.org/wec-geis/edc/.
[20] European Wind Energy Association (EWEA). Record growth for global wind power in 2002; 2002.
[21] Filon A. Renewable energy options—overview and trends. The 28th Annual Conference of the Solar Energy Society of Canada (SESCI) 2003 Conference, jointly organized by the Solar Energy Society of Canada and Queen's University, Kingston, Ontario, Canada, August 18–20, 2003.
[22] Government of Canada. Climate change plan for Canada. 2003.
[23] Government of Canada. Government of Canada announced $1 billion toward implementation of the climate change plan for Canada. News Release 2003;August 12.
[24] GreenHeat 2003, web site, http://www.greenheat.org.
[25] Hannes R. HAWT versus VAWT. Refocus 2003;July/August.
[26] International Small Hydro Atlas 2003, web site, http://www.small-hydro.com.
[27] Islam M, Fartaj A, Ting D. Vertical axis wind turbines: past initiatives & future prospects. The 28th Annual Conference of the Solar Energy Society of Canada (SESCI) 2003 Conference, jointly organized by the Solar Energy Society of Canada and Queen's University, Kingston, Ontario, Canada, August 18–20, 2003.
[28] Makower and Pernick. Clean tech: profits and potential; 2001. Available from: http://www.clean-edge.com.
[29] Natural Resources Canada. Photovoltaics for buildings: opportunities for Canada. Varennes, Québec, Canada, November 2000.
[30] Natural Resources Canada. Renewable energy in Canada: status report 2002. Ontario, Canada, March, 2002.
[31] Peace S. Why not vertical axis. Refocus 2003;May–June.
[32] Pembina Institute. Low-impact renewable energy policy in Canada: strengths, gaps and a path forward. Canada. February, 2003.

[33] Renewable Energy Database of International Energy Agency, 2003, http://library.iea.org/dbtw-wpd/exec/dbtwpub.dll.
[34] Research Group on the Global Future. Global Statistics. Germany: Center for Applied Policy Research, Munich University; 2003 http://www.cap.uni-muenchen.de/fgz/statistics/statistics03.htm.
[35] Soft VAWT Project, 2003, http://www.awts.pe.ca/soft_VAWT_project.htm.
[36] US Energy Information Administration. 2003, http://www.eia.doe.gov.
[37] United Nations Development Program. World energy assessment, New York, USA, 2000.
[38] United Nations Population Fund (UNFPA). State of world population 2001. Available from: http://www.unfpa.org/swp/2001/english/ch01.html.
[39] Wikipedia 2003, web site, http://en.wikipedia.org/wiki/2003_US-Canada_blackout.
[40] Windsight. Ontario could be wind energy leader. Newsletter of Canadian Wind Energy Association (CanWEA), September, 2002.
[41] World Commission on Environment and Development. Our common future. Oxford University Press; May 1987.
[42] World Energy Council. Survey of energy resources 2001, London, UK; 2001. Available from: http://www.worldenergy.org/wec-geis/edc/countries/Canada.asp.
[43] You KH, Leng G. Renewable energy in Canada's remote communities. Renewable Energy for Remote Communities Program, Natural Resources Canada; 2003.